Trade-off in Thermoelectric Generator design for vehicle application

ECM 2015

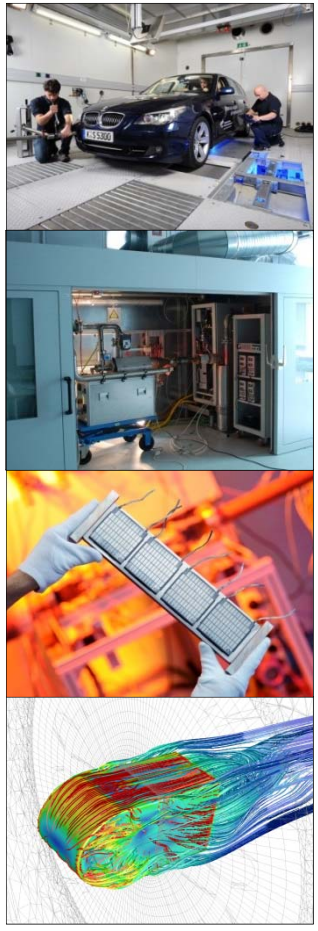
Aberdeen, 2015-08-11

Institute of Vehicle Concepts

K. Oetringer M. Eng.
M. Kober Dipl. Ing. (FH)

DLR

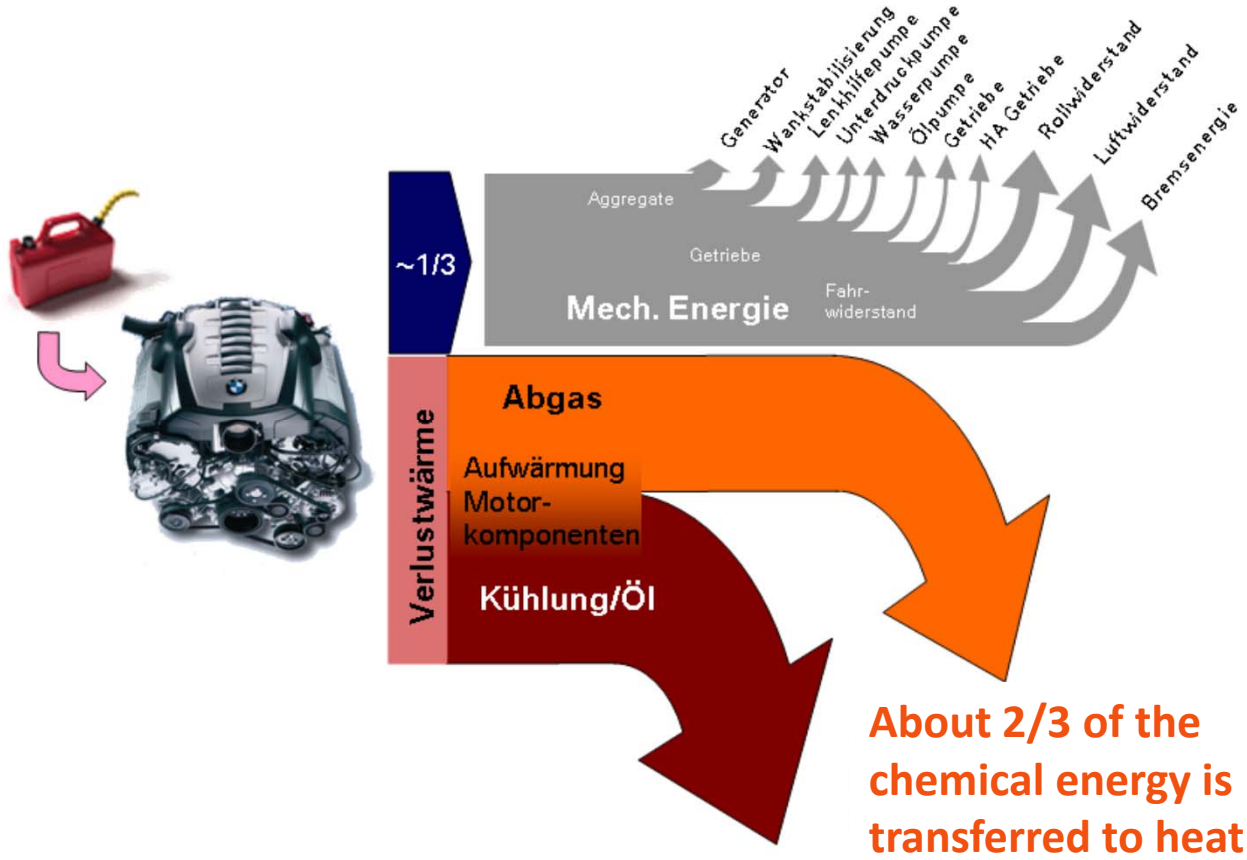
Outline



- Introduction
  - Motivation
  - Basics
  - TEG Evolution at DLR
- Optimization
  - Design-Point
  - Simulative Results
  - Validation by Measurement
- Outlook

Motivation for waste heat recovery

Basic combustion engine



About 2/3 of the chemical energy is transferred to heat

1) Treffinger P., Häfele Ch., Weiler T. DLR e.V. Stuttgart; Eder A., Richter R., Mazar B. BMW Group München: Energierückgewinnung durch Wandlung von Abwärme in Nutzenergie. 2008 VDI Tagung „Innovative Fahrzeugantriebe", Dresden

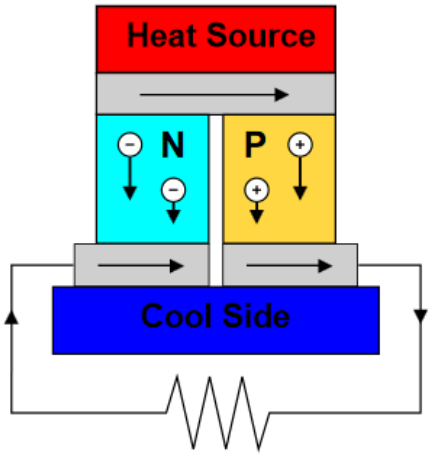
DLR

Basics of thermoelectricity

- thermal diffusion of electrons respectively holes to cold side
- Electric potential is proportional to ΔT:

$$S = \frac{U}{\Delta T}$$

S Seebeck-coefficient



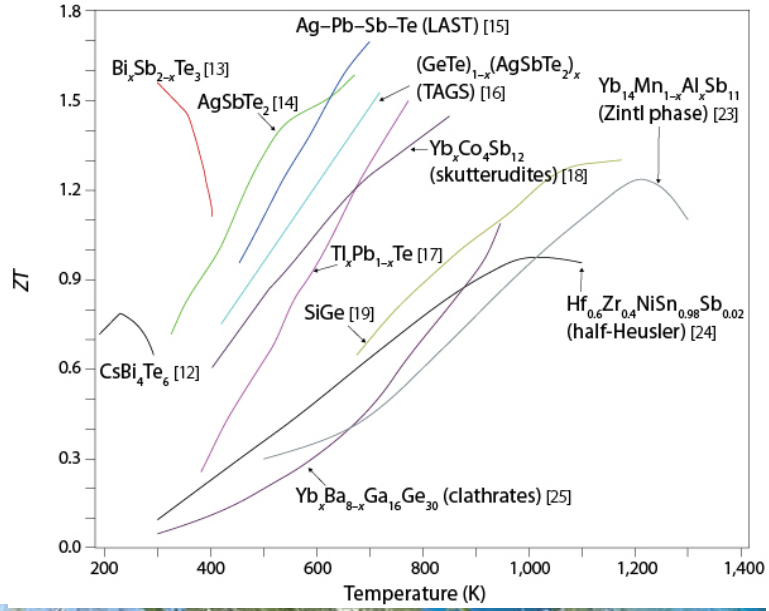
- Dimensionless figure of merit ZT:

$$ZT = \frac{S^2 \sigma}{\kappa} T$$

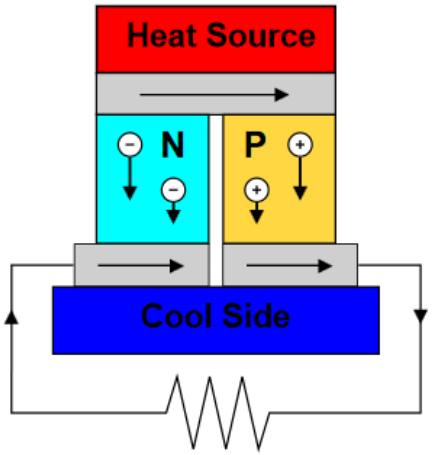
σ electrical conductivity
K thermal conductivity
T temperature

- Efficiency TE:

$$\eta = \frac{P_{el}}{\dot{Q}_{in}} = \frac{T_h - T_k}{T_h} \cdot \frac{\sqrt{ZT+1}-1}{\sqrt{ZT+1}+\frac{T_k}{T_h}}$$



Basics of thermoelectricity in application



- Electric potential is proportional to ΔT:

$$S = \frac{U}{\Delta T}$$

S Seebeck-coefficient

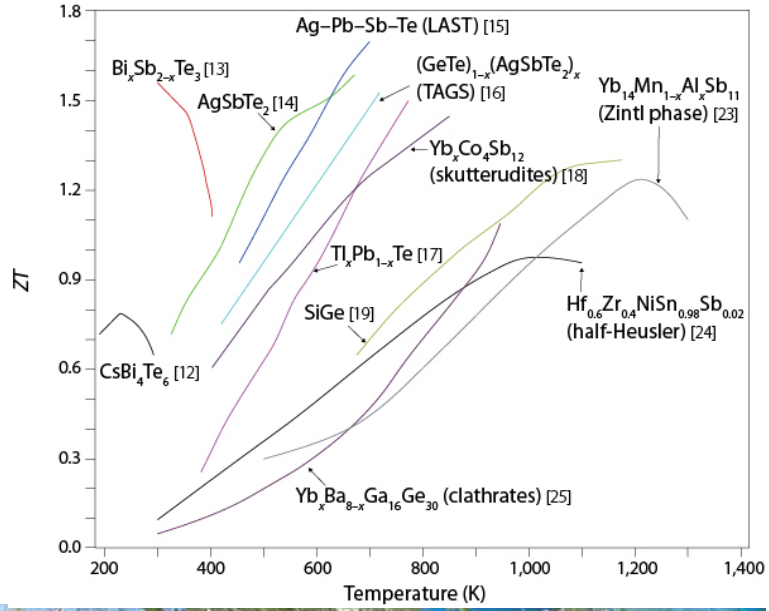
- Dimensionless figure of merit ZT:

$$ZT = \frac{S^2 \sigma}{\kappa} T$$

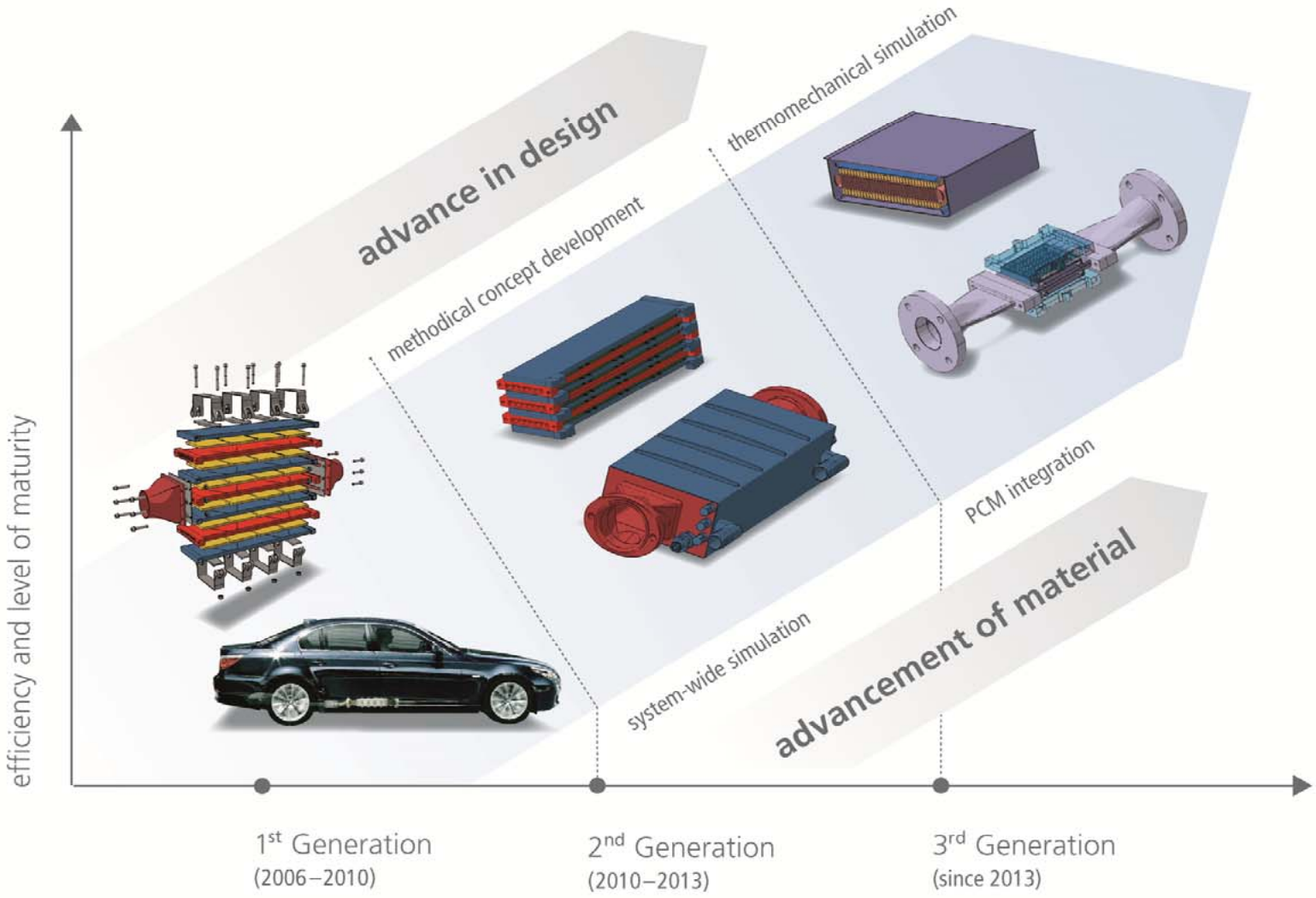
σ electrical conductivity
K thermal conductivity
T temperature

- Efficiency TE:

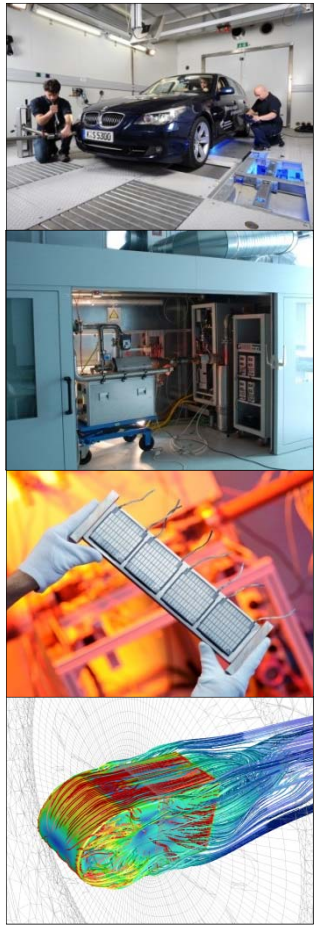
$$\eta = \frac{P_{el}}{\dot{Q}_{in}} = \frac{T_h - T_k}{T_h} \cdot \frac{1}{\frac{4}{ZT_h} + 2 - \frac{T_h - T_k}{2T_h}}$$



The Evolution of the TEG at the DLR



Outline



- Introduction
  - Motivation
  - Basics
  - TEG Evolution at DLR
- Optimization
  - Design-Point
  - Simulative Results
  - Validation by Measurement
- Outlook

Optimize the benefit for the application

electrical TEG input power (ΔP_{in})

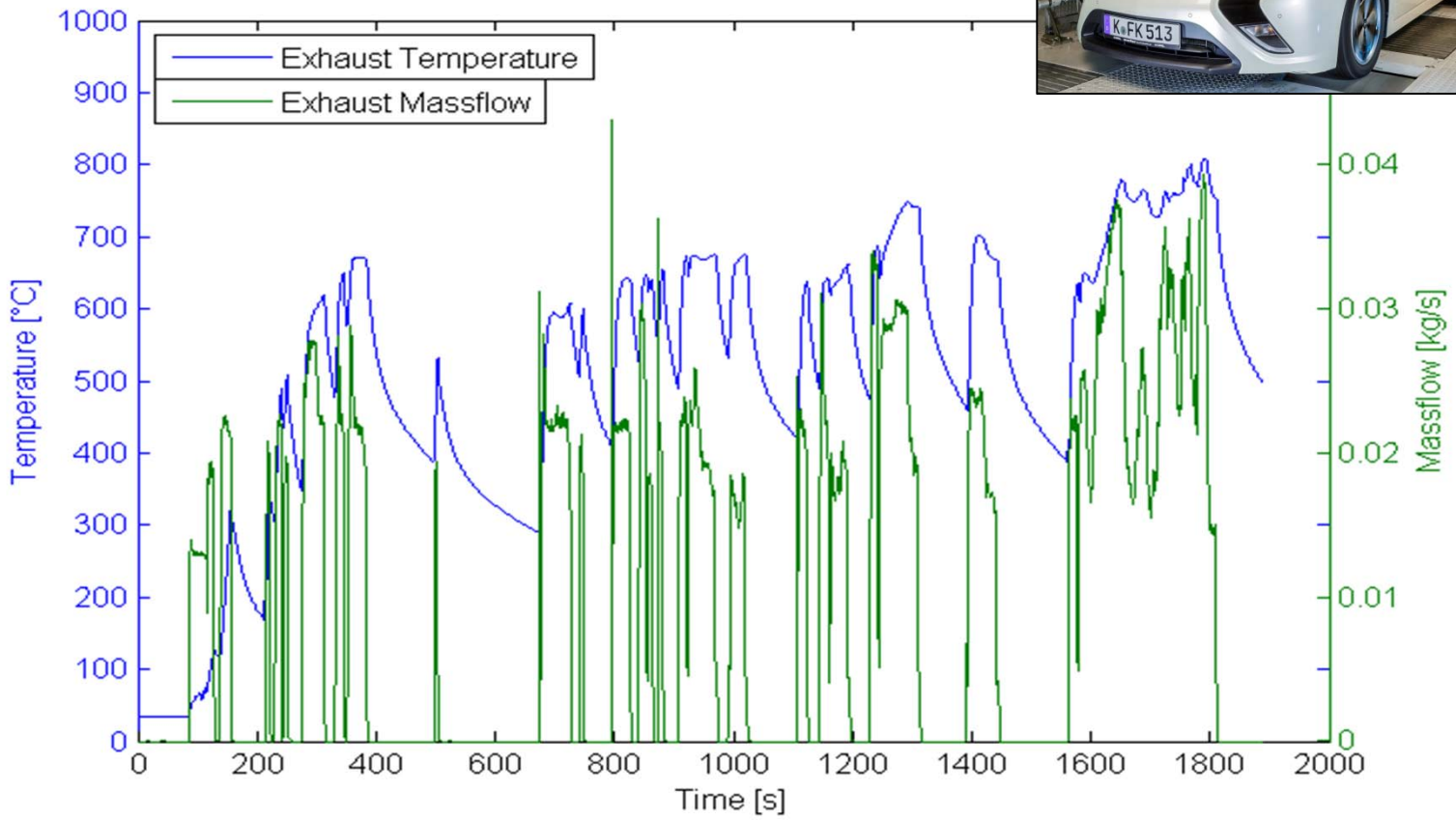
cooling load (ΔP_{co})
(el. power for cooling water pump and cooling fan, quick heat-up phase)

back pressure / cooling of exhaust (ΔP_{pr})

rolling resistance (ΔP_{ro})
(weight increase)

Choosing a Design-Point

Basic for Vehicle testing => WLTC



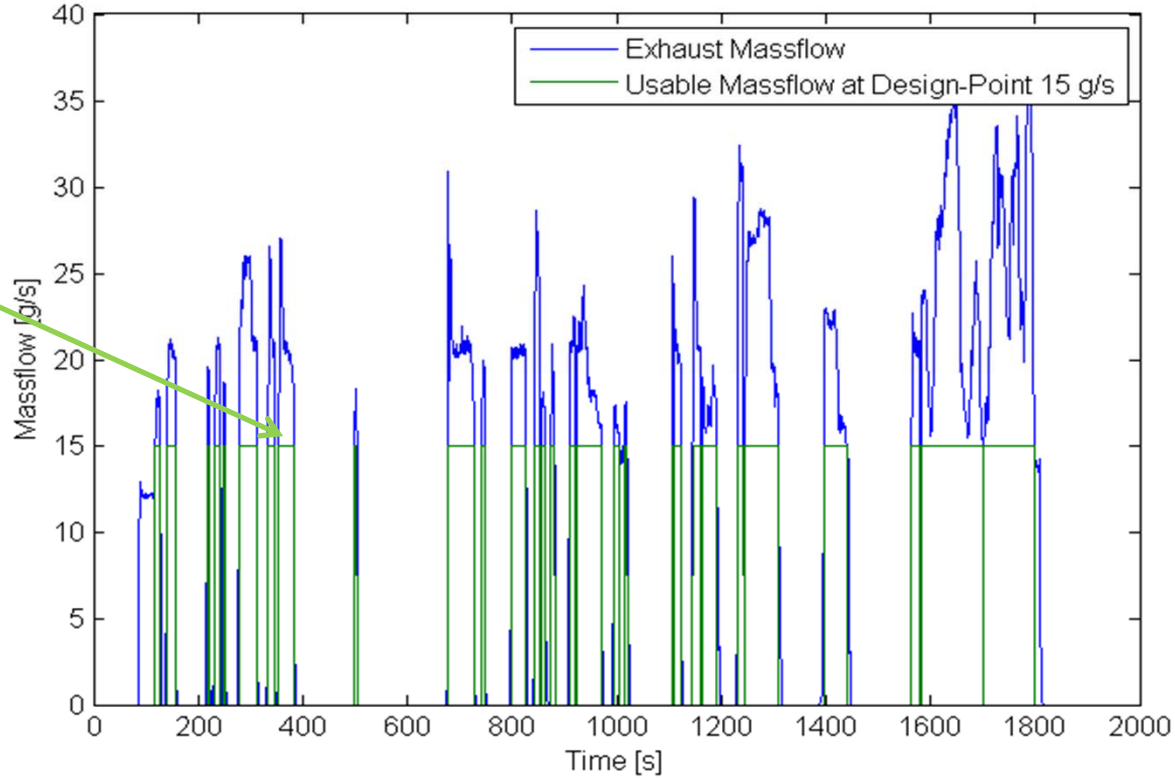
Choosing a Design-Point

Which Design-Point contains most energy?

possible Design-Point

15 g/s

400°C



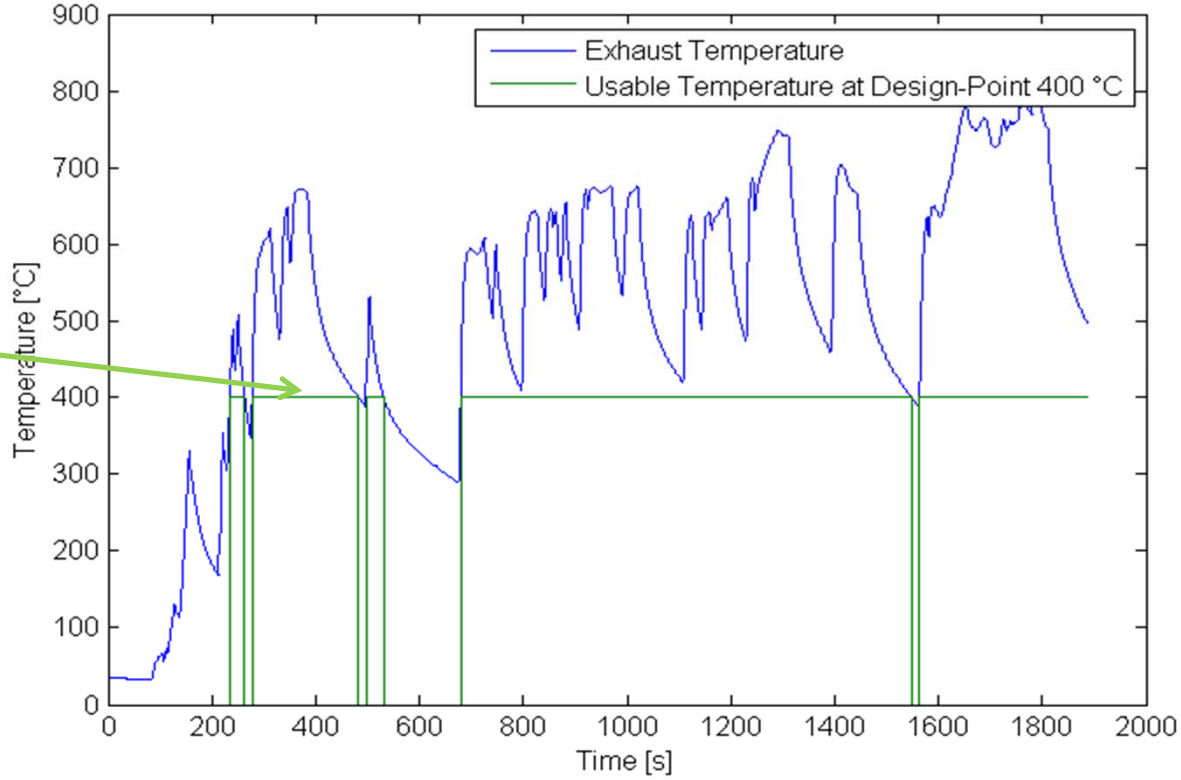
Choosing a Design-Point

Which Design-Point contains most energy?

possible Design-Point

15 g/s

400°C



Choosing a Design-Point

Which Design-Point contains most energy?

possible
Design-Point

15 g/s

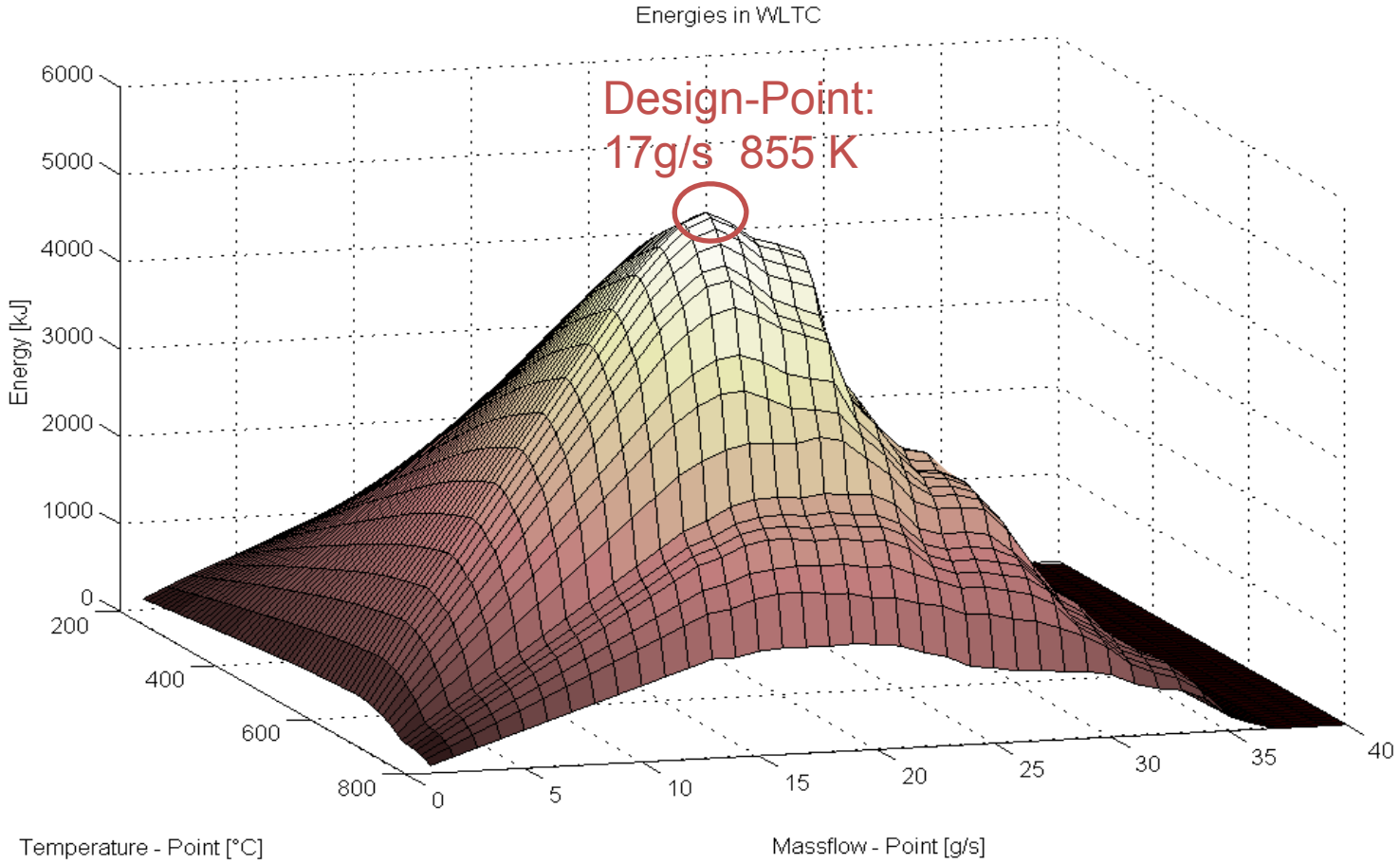
400°C

$$E = \int \dot{m}_u \cdot c_p \cdot (T_u - T_c)$$

E: Energy contained by Design Point
$\dot{m}_u$: usable Massflow
c_p: heat capacity of exhaust
T_u: usable Temperature
T_c: coldside Temperature of TEG

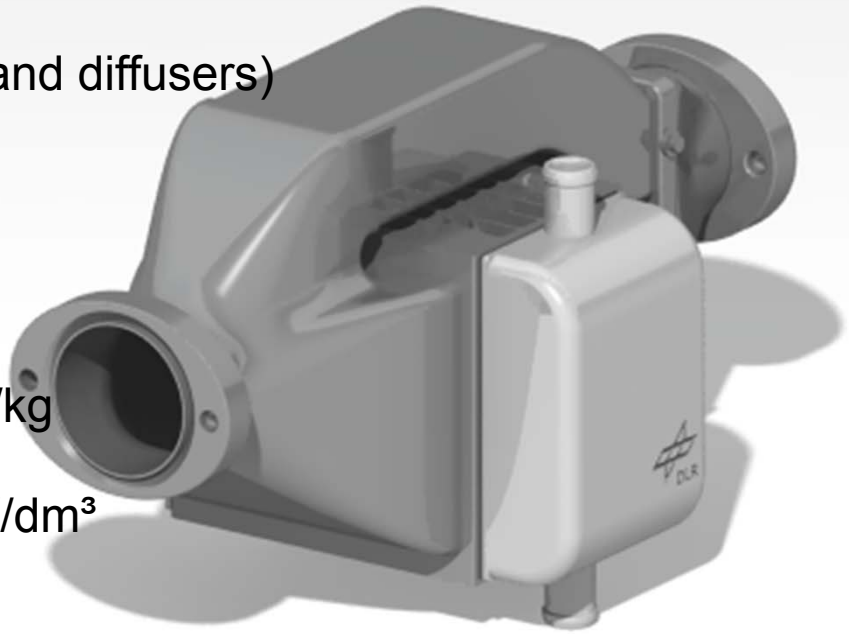
Choosing a Design-Point

Which Design-Point contains most energy?



Simulative results
Characteristics of the optimized TEG

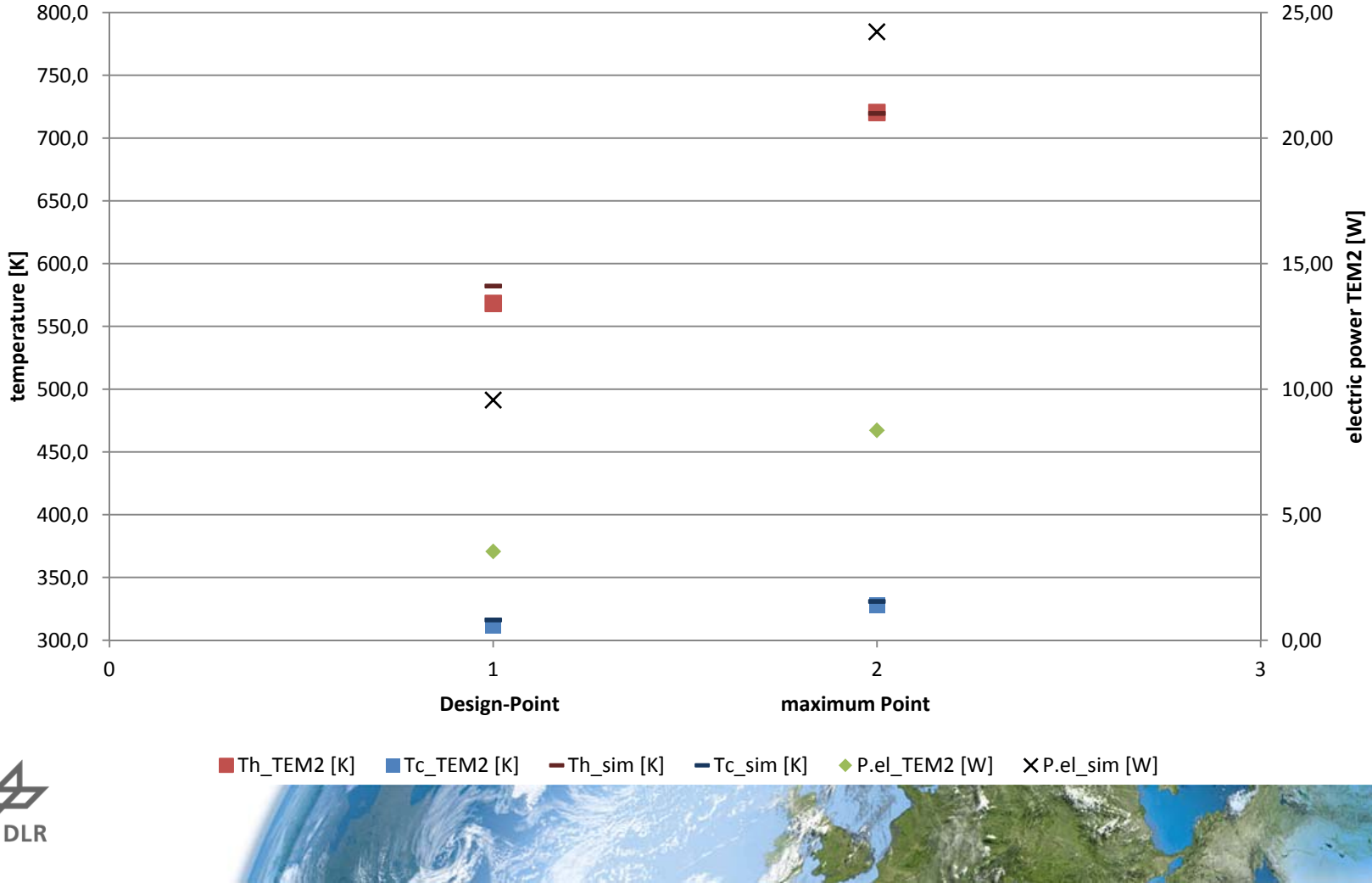
- weight < 8 kg (without bypass)
- volume < 3 dm³ (without bypass and diffusers)
- el. peak power > 400 W
- el. power at Design-Point > 160 W
- gravimetric power density > 50 W/kg
- volumetric power density > 133 W/dm³



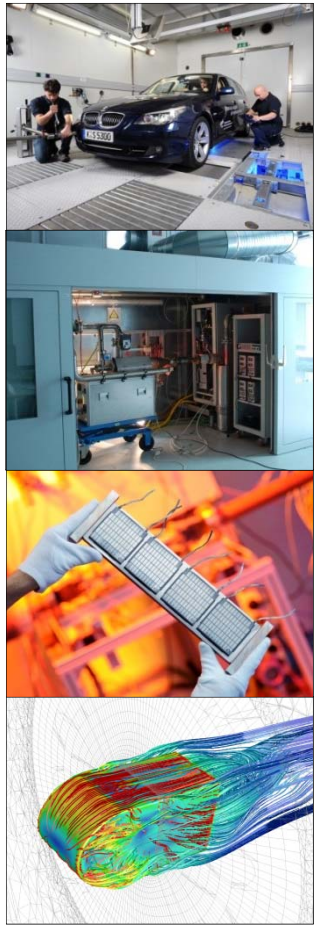
Measured results
Validation of simulation

Measured results

Validation of simulation



Outline



- Introduction
  - Motivation
  - Basics
  - TEG Evolution at DLR
- Optimization
  - Design-Point
  - Simulative Results
  - Validation by Measurement
- Outlook

Outlook / Summary

- Philosophy to success:
  - Maximizing the benefit for OEM and Driver
    => taking into account negative effects
  - Not maximizing the el. power output

- Reached goals:
  - Successful integration of high temperature modules
  - Validation of thermal simulation

- Outlook:
  - Dynamic simulation to simulate a whole driving cycle
  - Improve / research at high temperature modules

The Project RExTEG

Project aim:
Developing a new kind of Thermoelectric Generator increasing the efficiency of Range Extender and Hybrid Vehicles

DLR IFK

Fraunhofer IPM

Ministry of Finances and Economics
Baden-Württemberg

- Potentials
- Measuring vehicle
- Materials
- Concept development
- Simulation
- Functioning mock up
- Validation

DLR

Thank you for your attention!

Institute of Vehicle Concepts
Pfaffenwaldring 38-40
70569 Stuttgart

Kerstin Oetringer M. Eng.
Phone: 0049 - 711 6862 -516
kerstin.oetringer@dlr.de
www.DLR.de/fk